Usability Studies In Virtual And Traditional Computer Aided Design Environments For Spatial Awareness

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ABSTRACT

A usability study was used to measure user performance and user preferences for a CAVE™ immersive stereoscopic virtual environment with wand interfaces compared directly with a workstation non-stereoscopic traditional CAD interface with keyboard and mouse. In both the CAVE™ and the adaptable technology environments, crystal eye glasses are used to produce a stereoscopic view. An ascension flock of birds tracking system is used for tracking the user's head and wand pointing device positions in 3D space.

It is argued that with these immersive technologies, including the use of gestures and hand movements, a more natural interface in immersive virtual environments is possible. Such an interface allows a more rapid and efficient set of actions to recognize geometry, interaction within a spatial environment, the ability to find errors, and navigate through a virtual environment. The wand interface provides a significantly improved means of interaction. This study quantitatively measures the differences in interaction when compared with traditional human computer interfaces.

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It is argued that with these immersive technologies, including the use of gestures and hand movements, a more natural interface in immersive virtual environments is possible. Such an interface allows a more rapid and efficient set of actions to recognize geometry, interaction within a spatial environment, the ability to find errors, and navigate through a virtual environment. The wand interface provides a significantly

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This paper provides analysis via usability study methods for spatial awareness termed as Benchmark 3. During testing, testers are given some time to "play around" with the CAVE™ environment for familiarity before undertaking a specific exercise. The testers are then instructed regarding tasks to be completed, and are asked to work quickly without sacrificing accuracy. The research team timed each task, and recorded activity on evaluation sheets for spatial awareness Test. At the completion of the testing scenario involving spatial awareness, the subject/testers were given a survey document and asked to respond by checking boxes to communicate their subjective opinions.

Keywords: Usability Analysis; CAVE™ (Cave Automatic Virtual Environments); Human Computer Interface (HCI); Benchmark; Virtual Reality; Virtual Environments; Competitive Comparison

INTRODUCTION

This paper is an extension of the work done by Satter (2005) on Competitive Usability Studies of Virtual Environments for Shipbuilding. The key difference is the use of a new immersive environment called CAVE™. The significance and the detail description of this study is very well explained by Satter (2012) in his recent paper. Here we only present the details of this usability study. The CAVE™ was developed at the University of Illinois at Chicago and provides the illusion of immersion by projecting stereo images on the walls and floor of a room-sized cube. Several users wearing lightweight stereo glasses can enter and walk freely inside the CAVE™. A head tracking system continuously adjusts the stereo projection to the current position of the leading viewer. A CAVE™ and wand system schematic is shown in Figures 1 & 2.

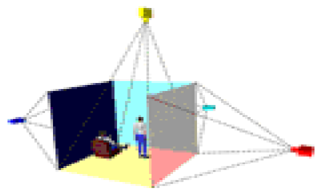


Figure 1: Schematic of the CAVE™ System

Figure 2: The Wand Interface

1. Description

In order to evaluate the ability of each environment/interface to aid users in their awareness of a design space, a unique space, totally unknown to the users, was created. For the test, the space created was a virtual factory space and a machine shop. Into this space the test administrators were able to inject an obelisk icon (an elongated, gray-white, pyramid topped by a sphere as shown below in figure 3) that is not normally found in any factory space. Two such icons were randomly placed into the new space for each pass of the test. From a common starting point, users were required to navigate through the space looking for the icons within the space. The time required each user to locate each icon was recorded and the users were asked to note the location for each (placement within the space).

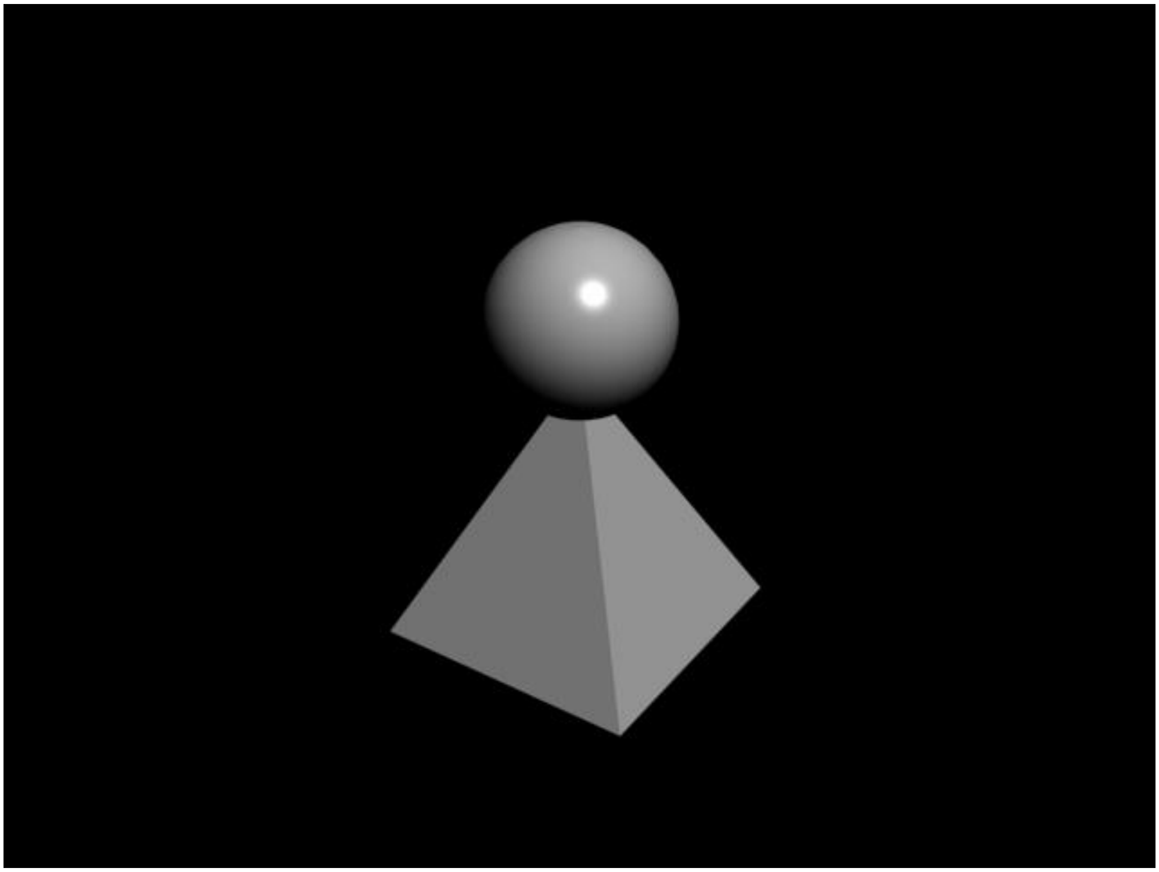


Figure 3: Icon

Upon completion of the test each user was shown a 2-dimensional, 8.5” x 11”, plan-view of the space and asked to note the placement of each of the two icons. The test administrators then recorded the offset (in mm) between user placement and the actual location of the icons.

This exercise (Benchmark 3) was repeated in each of the 2 environments and the User Survey administered to each user after each pass in each environment. As with the other Benchmark testing, sequencing of the testers through the two environments was randomized so that not all of the users were testing the same interface in the same order. This randomization was used to eliminate bias in the testing.

2. Benchmark 3, Pass 3, Part 1 & 2 Placement Offsets Analysis:

Following is a presentation of the Benchmark 3, pass 3, part 1 and part 2 placement offsets for all the users. Pass 3 results are presented here as representative of user best-final case results. All other results are presented in Appendix C [3].

Figure 4 (Benchmark 3 pass 3 Icon 1 Offsets / B3p3-1off) presents user placement of the first icon within the new space. The results clearly indicate a higher spatial awareness using the stereoscopic CAVE™ environment. Using the stereoscopic interface, users on average located the icon within 11 mm of its actual location. User's placement of the icon using the workstation non-stereoscopic environments was within 12.83 mm of its actual location.

Inspection of the standard deviation values of table 1 for the location of icon 1 shows a high variance in offset for the stereoscopic interface and shows low variance for the non-stereoscopic interface. This is an indication of the consistency of the non-stereoscopic method in spatial recognition efforts. Users were able to locate the icons better in workstation (2-dimensional non-stereoscopic environment) on a 2-dimensional, 8.5" x 11" paper than in a CAVE™.

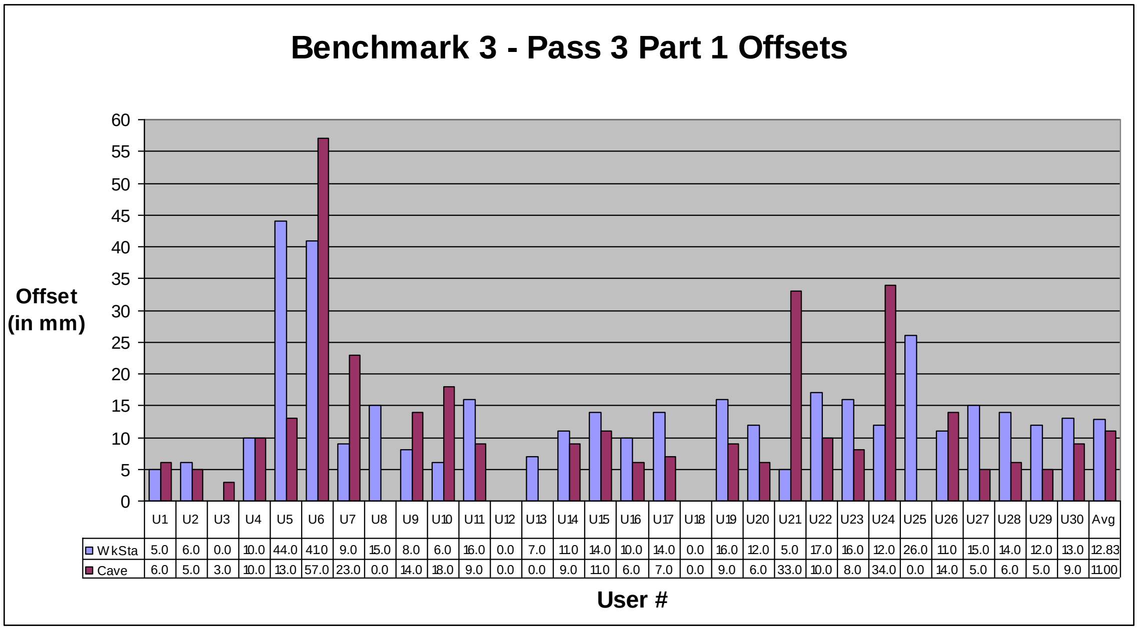


Figure 4: B3p3-1off Pass 3-Icon 1 Offsets

B3Part1P3	# Users	Mean	St. Dev.	Low	High	P Value	Normal?	CV
Cave	30	11	12.13	0	57	<0.10	No	110%
W/S	30	12.83	9.84	0	44	<0.10	No	77%
		Homogeneity of Variance			Test for Differences			
		Levene's Test		Equal Var?	Mann-Whitney Test		Equal?	Significant?
		F-Value	Pr > F		Value	Pr > T		
Cave vs W/S		0.2	0.65	Yes	5.75	<0.001	No	Cave

Table 1: B3p3-1off Pass 3-Icon 1 Offsets

Figure 5 (Benchmark 3 pass 3 Icon 2 Offsets / B3p3-2off) presents user placement of the second icon within the new space. The results clearly indicate a higher spatial awareness using the stereoscopic the CAVE™ environment. Using the stereoscopic interface users, on average, located the icon within 7.77 mm of its actual location. User placement of the icon using the workstation non-stereoscopic environments was within 13.8 mm of its actual location.

Inspection of the standard deviation values of table 2 for the location of icon 2 shows a high variance in offset for the non-stereoscopic interface and shows low variance for the stereoscopic interface. This is an indication of the consistency of the stereoscopic method in spatial recognition efforts. Users were able to locate the icons much better in the CAVE^{TM} environment than in a workstation. This proves that users performed better after practice in the CAVE^{TM} environment proving the significance usability analysis.

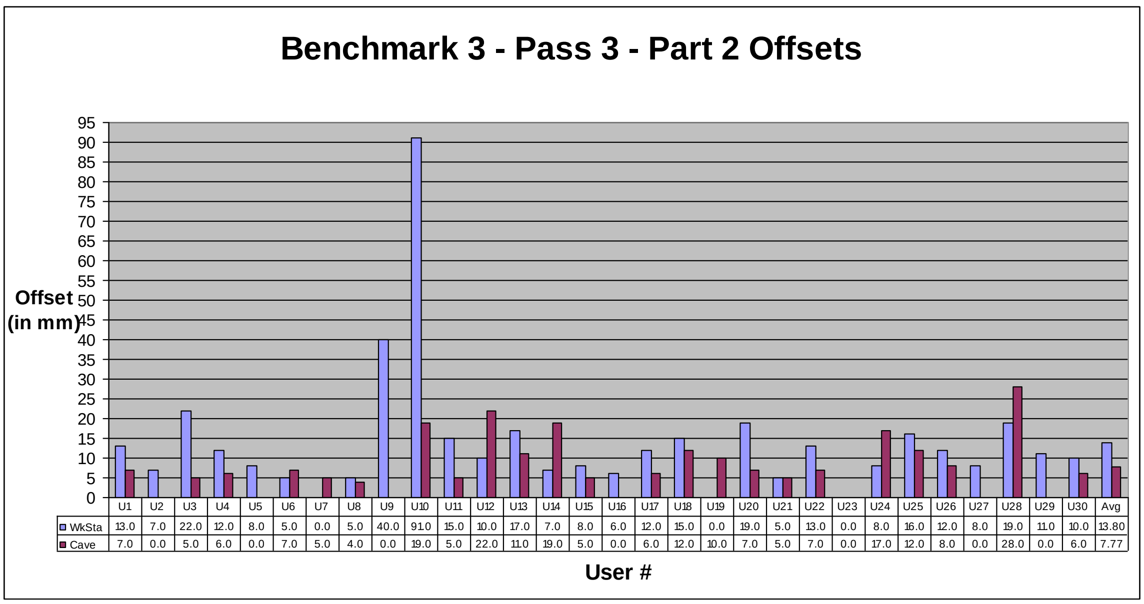


Figure 5: B3p3-2off Pass 3-Icon 2 Offsets

3. *Detailed Statistical Analysis*

The following sections present a detailed statistical analysis of the Benchmark 3 results of the user group in a manner similar to the previous Benchmarks. As discussed above, the NCSS software package was used to perform each analysis. Each set of user icon 2 placement offsets is first examined to determine if the data is normally distributed (Gaussian distribution) using the KS statistic. The descriptive statistics test results are presented in tabular form followed by the results of Levene's test for equal variance of the data. The null hypothesis (H_0) and alternative hypothesis (H_a) discussed for Benchmark 1 statistical analysis testing applies here (Benchmark 3) as well.

4. *Benchmark 3Pass 3 Statistics*

Benchmark 3, pass 3, icon 2 offsets represent each user's view of the placement of the required device in a foreign space. As such, the results of this pass/icon placement represent a reasonable characterization of the user's spatial awareness within each environment**.**

5. *B3p3-2off –Benchmark 3 Pass 3 Descriptive Statistics*

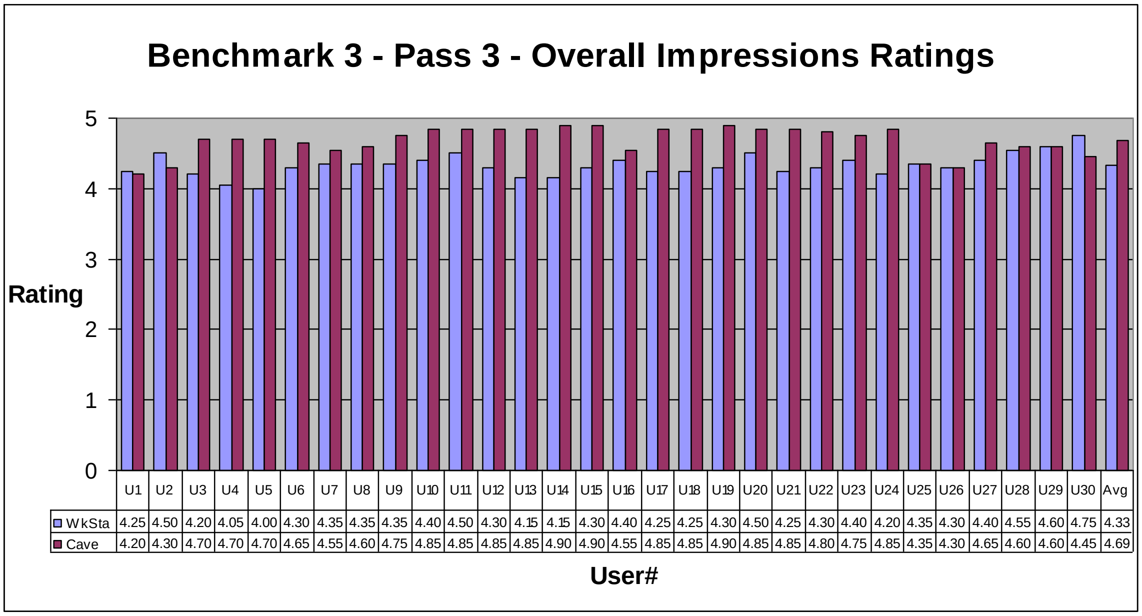
Table 2 presents the results of the descriptive statistics analysis of user's pass 3 location of icon 2 in the test environment. All other results are presented in Appendix C [3]. The K.S. test is used to test for normality of data. Since the P value is less than 0.1, the data is not normal. Next Levene's test is then applied to test for equal variance. Since the P value is greater than 0.1 the data has equal variance. Since the data is not normal, Mann Whitney test is used. A Mann Whitney test P value less than 0.1 indicates that medians are unequal for the CAVE™ and workstation. Examination of these results shows that for the two environments, the differences are statistically significant. The conclusion then is that at the 90% confidence level, there is significant evidence to support the

alternative hypothesis (H_a). Thus, since the stereoscopic wand environment demonstrates shorter offset distances, the CAVE™ environment is statistically "better" than non-stereoscopic workstation environment for Benchmark 3 during pass 3 for Icon 2 placements.

B3Part2P3	# Users	Mean	St. Dev.	Low	High	P Value	Normal?	CV
Cave	30	7.77	7.16	0	28	<0.10	No	92%
W/S	30	13.8	16.53	0	91	<0.10	No	120%
		Homogeneity of Variance			Test for Differences			
		Levene's Test		Equal	Mann-Whitney Test			
		F-Value	Pr > F	Var?	Value	Pr > T	Equal?	Significant?
Cave vs W/S		1.07	0.31	Yes	2.30	0.01	No	Cave

Table 2: B3p3-2off Pass 3-Icon 2 Offsets

Benchmark 3 Pass 3 Overall Impressions Ratings Analysis:



	U1	U2	U3	U4	U5	U6	U7	U8	U9	U10	U11	U12	U13	U14	U15	U16	U17	U18	U19	U20	U21	U22	U23	U24	U25	U26	U27	U28	U29	U30	Avg
WkSta	4.25	4.50	4.20	4.05	4.00	4.30	4.35	4.35	4.35	4.40	4.50	4.30	4.15	4.15	4.30	4.40	4.25	4.25	4.30	4.50	4.25	4.30	4.40	4.20	4.35	4.30	4.40	4.55	4.60	4.75	4.33
Cave	4.20	4.30	4.70	4.70	4.70	4.65	4.55	4.60	4.75	4.85	4.85	4.85	4.85	4.90	4.90	4.55	4.85	4.85	4.90	4.85	4.85	4.80	4.75	4.85	4.35	4.30	4.65	4.60	4.60	4.45	4.69

Figure 6: B3p3Ovr Pass 3 Overall Impressions Ratings

Figure 6 (Benchmark 3 pass 3 Overall Impressions Ratings / B3p3Ovr) graphically presents comparisons of the Benchmark 3 (spatial awareness) pass 3 overall ratings of the two environments. Inspection of the average ratings shows that users preferred the stereoscopic environment (CAVE^{TM}) over the non-stereoscopic environment (workstation).

6. Detailed Statistical Analysis

The following sections present a detailed statistical analysis of user overall impressions ratings of the two test environments following their 3rd and final pass of the Benchmark 3 scenario. All other results are presented in Appendix C[3] . The statistical analysis of these ratings provides insight into the final opinions of the users. As discussed above, the NCSS software package was used to perform each analysis. Each set of user overall impressions ratings is first examined to determine if the data are normally distributed (Gaussian distribution) using the KS statistic. The descriptive statistics test results are presented in tabular form followed by the results of Levene's test for equal variance of the data. The null hypothesis (H_0) and alternative hypothesis (H_a) discussed for Benchmark 1and 2 statistical analysis testing applies here (Benchmark 3) as well.

7. Benchmark 3 Pass 3 Overall Impressions Ratings Statistics

As noted, Benchmark 3, pass 3, overall impressions ratings represent each user's view of the placement of the required device in a foreign space. As such, these ratings represent a reasonable characterization of the user's overall impressions of the interfaces after the use of each to determine his/her spatial awareness of a previously unknown environment**.**

Table 3 presents the results of the descriptive statistics analysis of user's Benchmark 3 pass 3 overall impressions of the interface. The K.S. test is used to test for normality of data. Since the P value is less than 0.1 for the CAVE^{TM}, the data are not normal. Levene's test is used to test for equal variance and since the P value is greater than 0.1 the data have equal variance. Since the data is not normal, Mann Whitney test is used. With the Mann-Whitney test P value less than 0.1, which indicates that the medians are unequal for the CAVE^{TM} and workstation. Examination of

these results shows that for the two environments, the differences are statistically significant. The conclusion then is that at the 90% confidence level, there is significant evidence to support the alternative hypothesis (H_a). This proves that the CAVE^{TM} environment is preferred over workstation for Benchmark 3 pass 3 overall impressions subjective ratings.

B3OP3	# Users	Mean	St. Dev.	Low	High	P Value	Normal?	CV
Cave	30	4.69	0.2	4.2	4.90	<0.10	No	4.00%
W/S	30	4.33	0.16	4	4.75	>0.10	Yes	4.00%
		Homogeneity of Variance			Test for Differences			
		Levene's Test		Equal Var?	Mann-WhitneyTest		Equal?	Significant?
		F-Value	P Value		Value	P Value		
Cave vs W/S		2	0.16	Yes	-5.31	<0.001	No	Cave

Table 3: B3p3Ovr Pass 3 Overall Impressions Ratings Descriptive Statistics

8. Benchmark 3 Pass-to-Pass Comparison Analysis:

B3 Part1 Pass to Pass Comparison

	Pass1 to Pass2		Pass2 to Pass 3		Pass1 to Pass3	
	Diff	%	Diff	%	Diff	%
Cave	12.5	51%	1.03	9%	11.7	48%
W/S	14.7	49%	2.54	17%	17.27	57%

Table 4: B3I1 pass-to-pass Comparison of Offset distances

Table 4 presents pass-to-pass comparison of Benchmark 3 part 1/Icon 1 offsets. The positive values in table 4 prove that pass 1 offsets were greater than pass 2 and pass 2 offsets were greater than pass 3. This proves that user's placement of the icon on the paper improved from pass-to-pass with respect to the icon's exact location in the two test environments. For example a value of 57% for Workstation (pass 1 to pass 3) is calculated as (30.1-12.83)/30.1, where 30.1 and 12.83 represent the means of Benchmark 3 part 1/Icon 1 offsets for pass 1 and pass 3 respectively. From table 4

one can conclude that user's showed more improvement from pass to pass in workstation than in CAVE™. This is due to the fact that users were able to place the icons better in workstation (2-dimensional non-stereoscopic environment) on a 2-dimensional, 8.5" x 11" paper than in a CAVE™.

B3 Part2 Pass to Pass Comparison

	Pass1 to Pass2		Pass2 to Pass 3		Pass1 to Pass3	
	Diff	%	Diff	%	Diff	%
Cave	4.5	35%	0.53	6%	5.03	39%
W/S	11	39%	3.7	21%	14.6	51%

Table 5: B3I2 pass-to-pass Comparison of Offset distances

Table 5 (Benchmark 3 Icon 2 or part 2 pass-to-pass comparison / B3I2) presents pass-to-pass comparison of Benchmark 3 part 2/Icon 2 offsets. The positive values in table 5 prove that pass 1 offsets were greater than pass 2 and pass 2 offsets were greater than pass 3. For example a value of 51% for Workstation (pass 1 to pass 3) is calculated as (28.53-13.8)/28.53, where 28.53 and 13.8 represent the means of Benchmark 3 part 2/Icon 2 offsets for pass 1 and pass 3 respectively. From table 5 one can conclude that user's showed more improvement from pass to pass in workstation than in the CAVE™. This is due to the fact that users were able to place the icons better in workstation (2-dimensional non-stereoscopic environment) on a 2-dimensional, 8.5" x 11" paper than in a CAVE™.

B3 Overall Ratings Pass to Pass Comparison

	Pass1 to Pass2		Pass2 to Pass 3		Pass1 to Pass3	
	Diff	%	Diff	%	Diff	%
Cave	-0.82	-23%	-0.33	-8%	-1.15	-32%
W/S	-0.24	7%	-0.71	-20%	-0.95	-28%

Table 6: B3 Overall Impressions Ratings pass to pass Comparison

Table 6 presents pass-to-pass comparison of Benchmark 3 overall impressions subjective ratings. The negative values in table 6 prove that pass 1 ratings were lower than pass 2 and pass 2 ratings were lower than pass 3. For example a value of -28% for Workstation (pass 1 to pass 3) is calculated as (3.38-4.33)/3.38, where 3.38 and 4.33 represent the means of Benchmark 3 overall impressions ratings for pass 1 and pass 3 respectively. From table 6 one can conclude that the CAVE™ is preferred over workstation.

Usability Survey

User ID: ______

Environment: **19" CAD** **Stereo**

Pass: **1** **2** **3**

		Very Good 5	Good 4	Neutral 3	Poor 2	Very Poor 1
	Navigation					
1	Initial impression of navigational modes					
2	Gross control movement					
3	Speed of cursor/pointer movement					
4	Ability to make fine adjustments to the placement of the cursor/pointer					
5	Ability to recover cursor/pointer movements					
6	Ease of use					
7	After-test impression of the navigational modes					
	Locating					
1	Initial impression of the interface in locating specific parts/equipment					
2	Ease of identification of selected part/equipment					
3	Ability to make fine adjustments in selecting specific parts/equipment					
4	Ease of use					
5	After-test impression of the location/selection mechanism					
	Movement					
1	Initial impression of the interface for relocating parts/equipment					
2	Ease of movement across the three axis					
3	Ability to make fine part/equipment movement adjustments					
4	Ease of use					
5	After-test impression of the movement mechanism					
	General					
1	Initial impression of the overall system					
2	Ability to relate a 2D planform to the space as presented					
3	"Intuitiveness" of the interface - do the controls follow expected use?					
4	Overall ease of use					
5	After-test impression of the overall system.					

Comments

Figure 7: Usability Survey Questionnaire (Satter, 2005)

9. CONCLUSIONS

For Benchmark 3 (spatial awareness) the statistics shows better results (lower offset distances and higher subjective ratings) for the CAVE^{TM} in both objective and subjective measures than the workstation. We prove that the CAVE^{TM} is preferred over workstation by users.

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